Between Acoustic and Digital Pianos:

Sound and Key Touch (Static Touchweight, Escapement/Let Off, Inertia)

— Case Study —

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Introduction

Between his grand and digital pianos, Roberto certainly prefers the sound and the key touch of the grand. However, in consideration of other family members, he often needs to practice silently on the digital piano. So, an important question for him is how to effectively transfer skills between the two pianos. To answer this question, he started to explore the difference between these different types of pianos in some detail.

Also facing the possibility of downsizing to an apartment, he started to think about upgrading his digital piano so that he would keep only the new digital piano.

In this case study, we follow Roberto's experience, focusing on the sound and the key touch of acoustic and digital pianos. Although we mainly refer to just two specific models of pianos in a specific context, the description may still be useful for those who use both digital and acoustic pianos. Also, the information may be useful for those who are planning to buy and/or want to make the best out of a digital piano.

Disclaimer: This document describes the experience of Roberto, an untrained piano hobbyist. So, the information in this document must be regarded as such. Also, since Roberto likes Kawai pianos, his impression may be biased (though he/his family owns a bunch of Yamaha and Roland products).

About Roberto’s Pianos

Before proceeding, let us briefly introduce Roberto’s two pianos: Kawai grand piano GS-30 (6’1”) and Kawai digital piano ES100.

First, ES100 was Kawai’s least expensive portable digital piano, the predecessor to the current ES110. When introduced, ES100 received extremely good reviews from stores and users alike, especially within the price range. Actually, Roberto’s first piano was Yamaha P-45. Although he initially liked P-45, he gradually became dissatisfied with certain aspects of the key touch and the sound. So, after one year of use, he replaced it with ES100.

Later, Roberto got his GS-30. It is comparable to the current model of GX-3 and its predecessor, RX-3, and was said to compete with Yamaha C3. It was a sort of a special edition manufactured for a relatively short time. And as the model name, GS standing for Grand Supreme, suggests, it was a superior model above the KG series. Roberto’s GS-30 was built in 1982. He bought it used at an affordable price, because the piano store was about to abandon this trade-in item due to several cracks on the soundboard. Roberto was planning to fix them. However, after inserting pieces of paper/film in the space between the soundboard and ribs, the rattle/buzz subsided, at least to his satisfaction. He cleaned the piano, tuned it, regulated the action as much as he could, and also performed some voicing by sanding and needling the hammers, all by himself.

For Roberto, it was a very cost-effective way to enjoy the sound and the key touch of a decent-size grand piano. But there is a reason why he was able to do this. Prior to GS-30, he had a free vintage Lester petite grand (4’10”, ca. 1946). This piano became his training ground. He learned a lot about piano including tuning and maintenance. Unfortunately, there were many limitations to a grand piano this old and this small. Its bass sound suffered from the short bass strings. Its overall tone was a little too harsh, even after voicing. And the keys were not very responsive. So, when Roberto replaced it with GS-30, he was quite happy. Especially in comparison to the petite Lester, he felt as if GS-30 was a concert grand.

Sound

The sound of digital pianos have improved tremendously over the last several decades. Nowadays, virtually all digital pianos from major manufacturers come with the sounds of acclaimed concert grands. They sound very good, especially with headphones. So, how we feel about the sound of a particular digital piano may well depend on our preference of the sound source used in the model. However, there still are areas Roberto wanted to address.

When Roberto compares the sound of ES100 through headphones and that of GS-30, he feels very comfortable. They are alike. This may well reflect the fact that both instruments are made by Kawai. And in a sense, this is a good test for GS-30. That is, the salvaged GS-30 sounds comparable to the recorded concert grand (Kawai EX). This was not the case when he was using the petite Lester. He always felt that the Lester did not sound as good as ES100 through headphones. Since Roberto uses his digital piano mostly to practice silently, the sound from the headphones is pretty much all what he needs from ES100. However, he still wanted to check the sound from speakers.

First, as for the sound from ES100's internal speakers, Roberto thinks that it depends on the expectation. If ES100 is the only piano, not in comparison to any other, it may be all right. After all, it has a great sound from a concert grand. At the same time, the sound quality is limited by the internal sound production system, i.e., a weak amplifier and small speakers. Since Roberto has a decent grand piano, he clearly notices the limitations of ES100's internal sound production system. Of course, this situation is not specific to ES100. The sound from the internal speakers of all portable digital pianos simply cannot match that of acoustic pianos. For example, there is no way the small speakers of ES100 can produce the fundamental frequencies of the lowest octave of a piano (i.e., C2 and below, corresponding to frequencies about 65Hz and below). Note that what we hear from those low notes of a digital piano is mostly harmonics. Even most console digital pianos face the same issue. Probably the only exceptions are some of the most expensive digital pianos. For example, Roberto once heard the sound of Kawai CS11 in a showroom. He was impressed. However, if he can make noise, he would rather use an acoustic piano than a high-end digital piano.

Next, Roberto hooked up his ES100 to his audio system. It consists of Fosi Audio power amp (TDA7498E), Klipsch speakers (R-14M), and Yamaha subwoofer (YST-SW215), along with Behringer mini equalizer (FBQ800) and Rolls stereo mixer (Minimix 2). Items are neither expensive (cf. audiophile products) nor cheap (cf. computer audio products). The system can produce decent sound. Although the Fosi amp is advertised as 160 watts per channel, Roberto does not think it is actually capable of producing that much, especially with the relatively small power adapter that came with the amp. Nevertheless, it is more than enough for his needs. This configuration was sufficient to make the sound of ES100 even louder than that of GS-30. Looking at the spec of various digital pianos, Roberto thinks that the power needed to produce sounds as loud as acoustic pianos would be at least 20~40 watts per channel.

The frequency range of his Klipsch speakers can go down to about 60Hz. Thus, they can cover the fundamental frequencies of all the piano notes except for the lowest octave. Compared to the internal speakers, these speakers alone can produce much deeper bass sound. Then, the fundamental frequencies of the lowest octave can be produced by the Yamaha subwoofer. However, in order not to exaggerate the bass sound, he adjusted the cutoff frequency of the subwoofer very low. So, Roberto's audio system can produce the complete frequency range of the piano sound. The outcome is obvious. The sound from external speakers (and subwoofer) is far louder, richer, and more realistic than that from internal speakers.

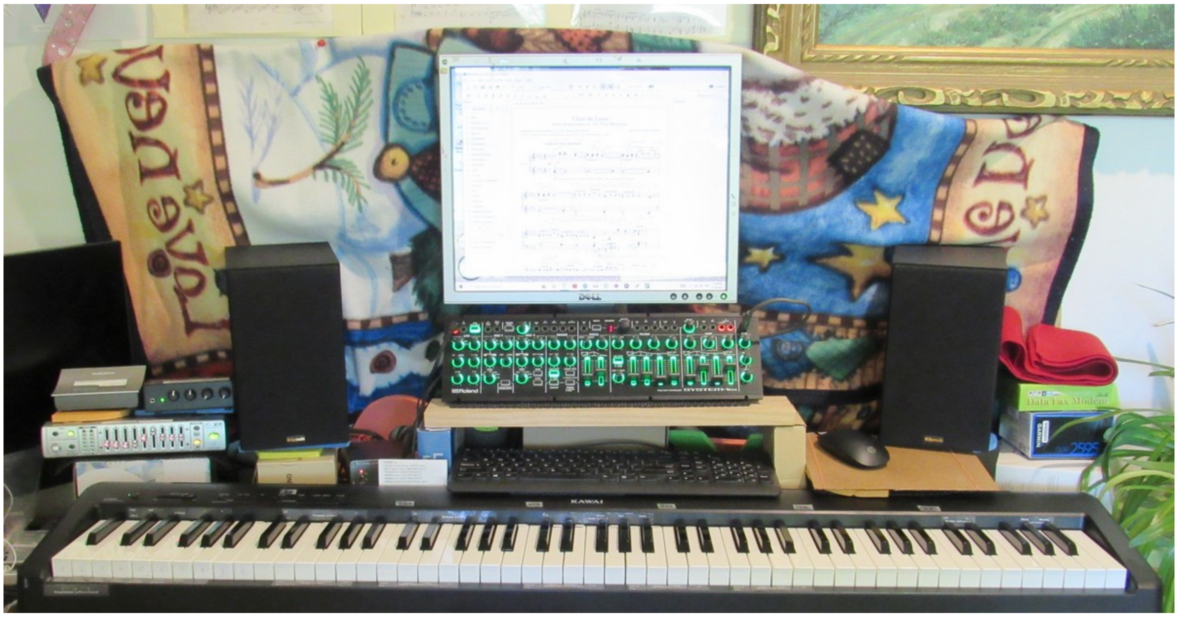
At this point, Roberto started to pay a closer attention to the quality of the sound from the external speakers. The most striking characteristic was that the mid range around C3-C5, i.e., mainly two octaves around the middle C, seemed muffled or muddy. This is in comparison to both the sound of ES100 using headphones and that of GS-30. Roberto also compared MuseScore piano sound through the headphones and external speakers. Again, the mid range from the external speakers sounded muffled. So, this is not a problem with ES100. Then, he realized that the mid range from ES100's internal speakers too is muffled. But we will not discuss internal speakers any more; Roberto simply does not use them.

Roberto's assumption up to this point was that the ES100 sound from headphones can be used as reference. But he thought he had better confirm this. First, his headphones (Superlux HD668B) are a budget product but they are considered excellent for the price. He checked their frequency response using the audio sweep sound on the web site called Audio Check (https://www.audiocheck.net/). For this test, he needed to set the sound level as low as possible. He could hear the sweep from around 20Hz to around 13kHz. Unfortunately, he can no longer hear higher frequencies due to mild hearing loss. Any way, the frequency response was fairly flat throughout, except that treble is slightly more pronounced. This was noted by some online reviewers as well (e.g., https://www.rtings.com/headphones/reviews/superlux/hd-668b). Just to compare, Roberto did the same test for his Behringer HPX2000 (less expensive than HD668B) as well. He felt that HPX2000 is weaker on the low and high ends. In addition, the sound level and the left-right balance fluctuate especially in the treble. So, he felt good about the sound from HD668B as the reference.

Now, back to the sound from external speakers. In comparison to the sound from headphones, the mid range is definitely muffled, even if the subwoofer is turned off. Roberto's guess was that the bass is exaggerated for some reason and as a result, the mid-range notes appear to lack enough harmonics for brightness. Roberto tried to confirm this point using the audio sweep sound. However, it is far trickier to test speakers this way. Unlike sounds from headphones, all sorts of complications get involved. In contrast, comparing the *quality* of piano sounds turned out to be a very good frequency response test. Until he checked the piano sound carefully, Roberto had never suspected that his audio system had a frequency response issue. This is because just listening to music casually can hardly tell the subtle tonal quality.

In order to test his hypothesis, Roberto used his equalizer. After reducing the level of the lower bands (below 1kHz) and increasing the level of the higher bands (above 1kHz), the mid-range became clearer and similar to the sound from headphones. So, he was convinced that bass is exaggerated. However, the difference between the highest and the lowest level on the equalizer reached almost 20dB (100 times!). This seemed too high. He thought that he needs to do something else before relying on the equalizer.

Then, Roberto turned to the room acoustics. He suspected that bass is exaggerated due to the way speakers are placed and the sound is reflected by the walls. In particular, he suspected the involvement of the large wall behind the speakers and the large window on the other side of the room. So, he adjusted the positions of the speakers and placed a blanket between the speakers and the wall, so that the sound is somewhat absorbed by the blanket. This setup is shown in the following image.



This seems to have worked. The mid range became less muffled. Still, Roberto had to use the equalizer for some more adjustment. But this time, the difference between the highest and the lowest level was about 10dB (10 times).

During this process, Roberto noticed one more issue. When he plays the notes around C5 (one octave above the middle C), there was a slight buzz from the right speaker. He tightened the connectors for the speaker wires. It seemed better but there still was buzz. So, in order to isolate the problem, he switched the right and the left speakers. For whatever reason, the buzz disappeared. Dealing with sound can be tricky.

With these experiments and adjustments, Roberto is more or less satisfied with the sound of ES100 from the external speakers and subwoofer. Now, it is comparable to the sound from the headphones. This process turned out to be much more complicated than he thought. But it was a good opportunity to fix the unnoticed issue with his audio system.

Another point is that it is in general more difficult to adjust the sound from the *internal* speakers. First, Roberto does not have the luxury of placing a digital piano at a position with ideal room acoustics. Then, ES100 does not have much to adjust its tonal quality from the internal speakers. And if he did change, say, brightness, it will also affect the sound from headphones. So, it really makes more sense to use external speakers and adjust the sound outside the digital piano.

Key Touch: Static Touchweight

For Roberto, the single most important aspect of a digital piano is the key touch. Of course, the keyboard actions/mechanisms are completely different between acoustic and digital pianos. So, it is natural that the key touch is very different. However, it was rather difficult for Robert to describe the difference in concrete terms.

So, Roberto began his exploration by visiting a web page called, “The Definitive Digital Piano Keyboard Touch Experiment” (https://www.sweetwater.com/insync/keyboard-action-and-key-weight-experiment/). Although he was skeptical about how “definitive” the experiment was, he thought that it can be a starting point.

The web page’s method uses gram weights. “We placed these gram weights on middle C while holding the key in the neutral position .... We then released the key and allowed it to drop to the depressed position and listened for middle C to sound.” Then, their reference piano, Yamaha S6X acoustic grand piano (7’), measures at 93 grams. Most of the tested digital pianos range from 72 to 105 grams. ES110 (successor of ES100) is at 85 grams. Note that this kind of touch weight is different from the measurement used by piano technicians dealing with acoustic pianos (more later). So, Roberto called this *Sounding Downweight* (**SdDW**) to distinguish from other measurements.

Next, Roberto used this method to test his pianos. Since he does not have gram weights, he used nickles (5 grams each) and pennies (2.5 grams each). He realized that stacking coins was fairly tricky. So, he taped some coins to make heavier stocks. Roberto’s measurement of his pianos was as follows:

- **GS-30**: About 95grams (without the damper pedal)
- **ES100**: About 95grams on white keys; about 75 grams on black keys

Both of these (except for the black keys on ES100) are more or less in the middle of the range listed on the web page. One striking point is that this simple test revealed the difference between the white and black keys of ES100. It was a big surprise for Roberto and he was rather disappointed. If Roberto had known this, he might have avoided ES100. But for now, he has to live with it. By the way, an analogous case was reported for certain models of Casio digital pianos (https://www.youtube.com/watch?v=OB9tqkPKdeU). However, ES110 (the successor of ES100) does not seem to have this problem (https://www.youtube.com/watch?v=ChMHi2auG_c). Note that ES100 has a key action called AHA IV-F, while ES110 has a newer action called RHC.

Then, Roberto measured the sounding downweight of GS-30 with the damper pedal depressed. It was about 70 grams. Well, how many of piano players know and/or notice that keys are lighter with the damper pedal depressed? If they do not even notice, say, 25 grams of **SdDW** difference depending on the use of damper pedal, the player's perception of touch weight may not be that precise.

As for Roberto's pianos, the weight of the ES100 white keys are comparable to that of GS-30 keys *without* the damper pedal; the weight of the ES100 black keys are comparable to the GS-30 keys *with* the damper pedal. Roberto never noticed 25 grams of **SdDW** difference in any of these different cases.

Since piano technicians use different static touchweight measurements, Roberto thought that he would try them as well. He turned to the most comprehensive book on piano maintenance, *Pianos Inside Out* by Mario Igrec (2013, http://www.pianosinsideout.com/). Here are just two ways of measuring static touchweight discussed in the book.

- *Downweight* (**DW**): "For both white and black keys, place weights on the front of the key ... so that the center of the weight is 13 mm in from the front edge. ... If the action is in the piano, *keep the damper pedal depressed*. Push the key down approximately 4 mm. The least amount of weight that makes the key slowly drop from that point is the downweight."

- *Upweight* (**UW**): "Hold the damper pedal depressed and depress the key to the point of increased resistance (7-8 mm). Starting with about 20 grams, place the weights on the standard measurement position and release the key. Adjust the weights until the key barely returns to the 4 mm point."

As for the description "the point of increased resistance," we will come back to it the next section on escapement.

The above-mentioned measurements are for acoustic pianos and are not directly applicable to digital pianos. But Roberto tried to simulate the measurement on his ES100 as well. Now, both of **DW** and **UW** are measured with the damper pedal depressed. However, as discussed earlier, on digital pianos, the use of damper pedal has absolutely no impact on the key touch/weight (there is one exception, to which we will return). So, for comparison purposes, Roberto also measured **DW** and **UW** of GS-30 without the damper pedal. Where necessary, we will distinguish the use of damper pedal as $\mathbf{DW}_{\text{w/pedal}}$ vs. $\mathbf{DW}_{\text{w/o-pedal}}$ and $\mathbf{UW}_{\text{w/pedal}}$ vs. $\mathbf{Uw}_{\text{w/o-pedal}}$.

First, Roberto measured **DW** and **UW** on C3, C4, and C5 of GS-30 and averaged the values, both with and without the damper pedal. Then, he measured **DW** and **UW** on C3, C4, and C5 of ES100 and averaged them. Finally, he measured **DW** on C#4 of ES100. He could not measure the **UW** on black keys; it was too tricky. Here is the results.

	GS-30		ES100	
	With damper pedal	Without damper pedal	White keys	C#4
DW	44	68	67	55
UW	34	53	56	Not measured
Unit of measurement: grams				

According to Igrec (2013), a typical $\mathbf{DW}_{\text{w/pedal}}$ value around the middle C is 45, within the range from 41 to 53, a typical $\mathbf{UW}_{\text{w/pedal}}$ value is 29, within the range from 21 to 33. So, the values for GS-30 seem all right (the **UW** seems a little too high, though). Without the damper pedal, the values for GS-30 and ES100 white keys are comparable. However, just like the case with **SdDW** (as discussed earlier), ES100 black keys are certainly lighter than white keys. It is just about the middle point between $\mathrm{D}\mathbf{W}_{\text{w/o-pedal}}$ and $\mathbf{DW}_{\text{w/pedal}}$ of GS-30, but not so much as the earlier **SdDW** measurement.

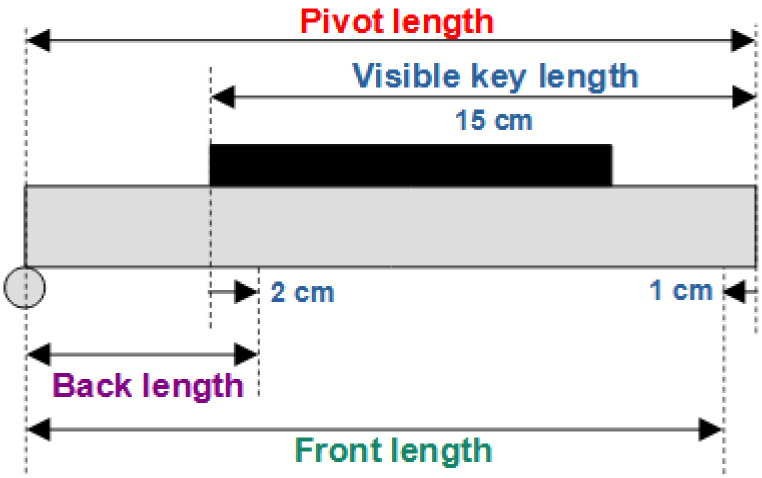
Then, Roberto came to think that this much of variation in static touchweight may not be as critical as he initially thought. In many cases, the player may not even notice. Even if variation is noticeable, the player might be able to accommodate it. There must be properties way more critical for his investigation.

At this point, Roberto recalled one of the reasons why he replaced Yamaha P-45 with ES100. It was the difference in “heaviness” between the front and the back of each key. Recently, he learned that this property is called ***touchpoint difference*** (Igrec 2013, pp. 301). On P-45, the touchpoint difference was rather big and this made it difficult to play the type of music Roberto was practicing. He felt that ES100 is much better in this respect.

Not surprisingly, this is not at all an issue with GS-30. On grand pianos, keys are very long and pivoted far back from the visible part of the key. As a result, touchpoint difference is smaller. However, even grand piano keys are typically twice as heavier on the back as on the front of a key.

As for digital pianos, touchpoint difference varies greatly among models. Unlike grand pianos' "seesaw" keys, most digital pianos embed some sort of simulated hammer mechanism which is "folded" beneath the key. This seems to be a reasonable solution to squeeze the action within a small space. Furthermore, keys are usually pivoted not far back from the visible end of the key. This increases the touchpoint difference.

Then, Roberto found useful information on a web page (http://forum.pianoworld.com/ubbthreads.php/topics/2732948/re-roland-lx-17-action.html#Post2732948). There, touchpoint difference is characterized in terms of the pivot length and force ratio. Since basically all piano keys (white) are 15 cm, this number can be used to calculate the force ratio between the touchweights at the front and at the back of a key (white). More details are shown in the following diagram.

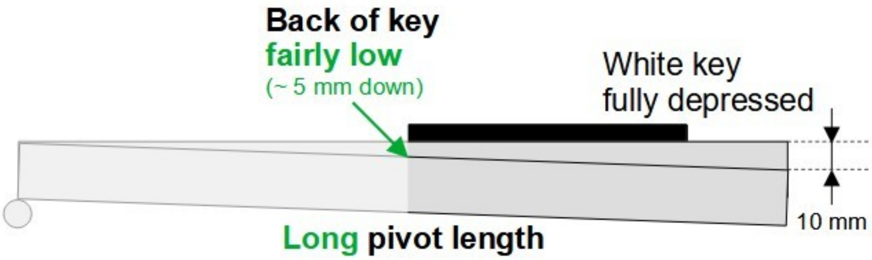


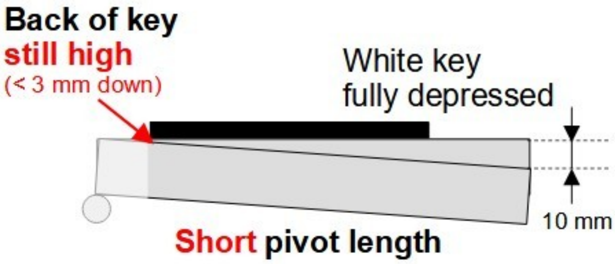
Force Ratio = Front length / Back length

The force ratio values shown on the web page range from about two (best, i.e., similar to grand pianos) to about four (worst). For example, the GHS action in P-45 is reported to have the force ratio of 3.8 (3.4 based on different information). Then, if the front **SdDW** measurement is 84 grams, the back touchweight can be around 300 grams. This appears huge and must be much more significance than the variation among front touchweights. In comparison, the AHA IV-F action in ES100 has the pivot length of about 21.5 cm (according to https://kawaius.com/technology/wooden-key-actions/) and thus the force ratio of 2.4. This is far better. Actually, AHA IV-F seems to be better than Kawai's newer actions, e.g., RHC and RH III. So, at least on this account, Roberto's reasoning for replacing P-45 with ES100 seems justified.

Once we understand the idea about touchpoint difference, it is fairly straightforward to assess this property. For example, if there is a side-way image of a key action (e.g., found online), it is possible to find out the pivot length in comparison to the standard 15-cm visible key length. Then, we can also calculate the force ratio. Or, if we are in a store, we can simply press the front and the back of each key (manual test). If the force ratio is around 3 or greater (poor), the difference is unmistakable.

Another quick and easy way is to observe the slope of a white key when fully depressed. The steeper, the worse. Or, it can also be estimated by how high the back of the depressed key remains, as seen in the following diagram (**Key Slope Test**).





A back key drop of 5 mm would correspond to the force ratio of 2 (comparable to a grand piano action). After this consideration, Roberto came to think that touchpoint difference is a bigger issue than just comparing touchweight at the front of a key. In fact, for those who use the back of keys a lot, this can be the number one property to check. And it is fairly easy to check. At this point, Roberto was somewhat comforted. Although he was initially upset about the touchweight difference between the white and black keys of ES100, he now thinks that it may not be as big an issue. In this respect, the web page "The Definitive Digital Piano Keyboard Touch Experiment" is *definitely not* "definitive." So, Roberto moved on.

Key Touch: Escapement

Roberto's next focus was the essential part of piano keyboard action called *escapement*. He also saw the term *let off* and was confused by these two terms, even after visiting various web pages on this topic.

Roberto also learned that the escapement mechanism is related to how acoustic piano keys feel, as in the description of **UW** in Igrec (2013), "the point of increased resistance (7-8 mm)" (p. 276) while the key is being depressed. Now, due to its central role in the piano key action, more and more digital piano manufacturers include some sort of escapement (or let off) simulation feature. For example, in the description of the new Kawai ES920, "let-off simulation recreates the subtle 'notch' sensation felt when softly playing the keys of a grand piano."

So, Roberto certainly felt the need to learn more about the mechanism. First, he looked up the following three relevant terms in the glossary section of Igrec (2013).

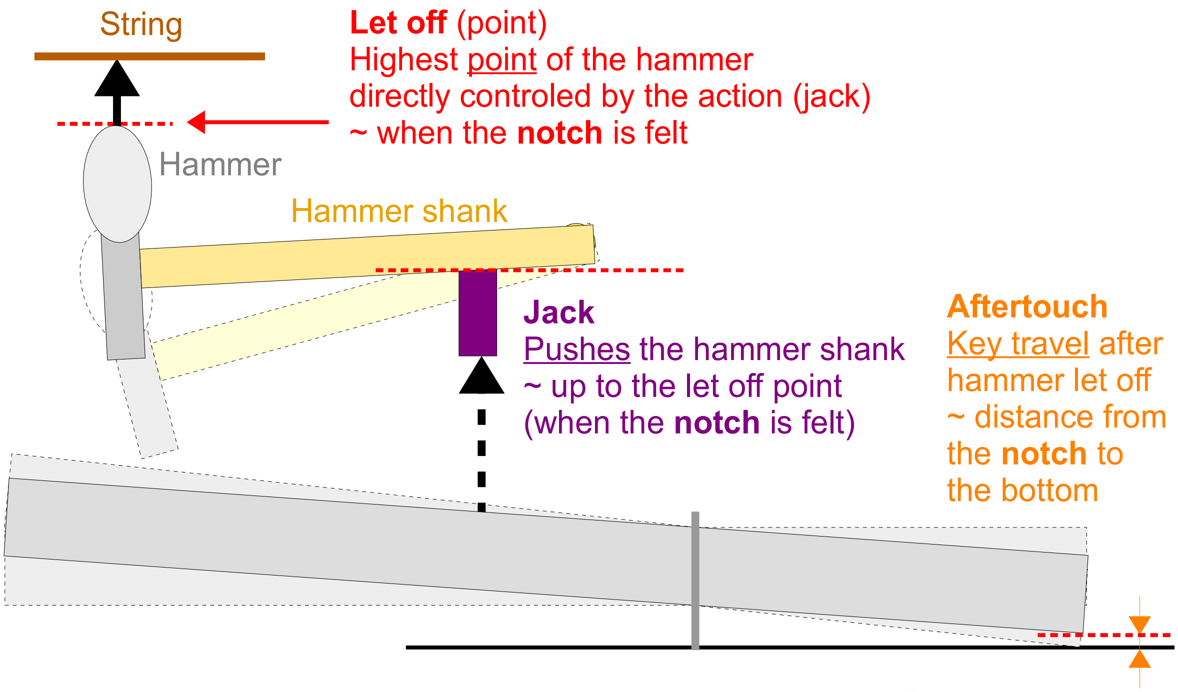
- **Escapement**: "Feature of all ... piano actions that allows hammers to rebound from strings regardless of the force or type of touch with which the keys are struck."
- **Let off**: "The highest point (closest to the strings) of the hammer travel supported by the jack." [about 1.5 mm below the string (p. 171)]
- **Aftertouch**: "Measurement of the vertical key travel after hammer let off." [0.8~1.5 mm (p. 173)]

Although *let off* is defined as "point" in the glossary, the author also describes it as "distance" on another page: "Let off is the distance between the strings and the highest point of the hammer's travel still supported by the jack." (p. 171) So, Roberto thought that it seems to make more sense to treat the term *let off* as a state at the end of the escapement process. Then, it would be possible to refer to the point associated with let off as let off *point*, and the mechanism (leading to that point) as let off *mechanism*. As far as he is concerned, the let off mechanism and the escapement mechanism do not need to be distinguished, possibly except for the following points.

- For grand pianos with "double escapement" (i.e., with repetition levers), the term *escapement mechanism* could involve both the let off mechanism *and* another one involving the repetition lever. So, strictly speaking, escapement and let off (mechanisms) are not identical.
- In the MIDI context, the term *aftertouch* is used in a rather different way.

Then, Roberto went on to summarize his understanding by creating the following diagram.

Escapement (~ let off mechanism)
Mechanism of releasing the hammer (shank) from the action (jack), so that the accelerated hammer can rebound after hitting the string
~ associated with a slight increase in resistance (**notch**/bump) during the key press



The red dashed lines are all associated with the let off point (and the **notch** during the key press).

While thinking about the mechanism, Roberto came up with the following analogy. The piano action is somewhat like throwing a ball to hit a gong (although no need to be precise about the course of the ball). That is, the player has control only up to the point of releasing the ball. When the ball hits the gong, the sound is made but how it sounds essentially depends on the control before the ball release.

So, piano action is an *indirect* mechanism of hitting strings. Of course, keys also control dampers (except for higher notes). And as a result, this combination creates the “illusion” of keys working like a switch. In addition, only about 10 mm of key travel actuates the hammer’s travel of around 50 mm. While this kind of leverage can exert speed, it will also require fine-tuned control. Roberto started to think that the subtle nuance of piano playing may well depend on this kind of indirectness involved in the escapement mechanism.

This situation contrasts with other keyboard instruments, such as organs and harpsichords. Organ keys are actually switches (electronic or mechanical). The player has *direct* control over whether or not the sound is being produced (but with no other control, e.g., loudness). Harpsichord keys push the jack and the "stick" on the jack plucks the string. The player has direct connection to the act of plucking, just like guitarists and harpists.

Reflecting on this, it seems natural that digital piano manufacturers are targeting the escapement mechanism as the next selling point. However, the common approach is simply to add a "bump" or "notch" to key touch (e.g., as can be seen on Kawai's web page listed earlier). However, Roberto's hunch was that this kind of trick may not add much authenticity to key touch. To him, it's like emulating crème brûlée with just sugar.

By this time, Roberto understood why he had difficulty playing soft notes on acoustic pianos. In fact, he had not even realized the indirect nature of piano key action. Now, playing soft does no longer appear to him as just depressing keys softly. It is the art of touching keys fast and strong enough for the hammer to move and reach the strings but gentle enough for the strings to make sounds at the intended level. In addition, this would also depend on a particular piano and a particular way of regulation.

After learning the basics of the escapement mechanism, Roberto was convinced about the importance of the *initial* part of key press (prior to the let off point) for producing sounds, especially soft sounds. Reflecting on this, he tried to measure the minimal key travel from the original position to produce a sound. To do this, he placed a stack of coins in front of a key to stop the key from moving further down. Note that this cannot be done with so-called "waterfall" keys without the protruding edge. The results for his pianos were as follows.

- GS-30: about 2 mm
- ES100: about 5 mm (about half way to the key bottom)

This does *not* necessarily mean that ES100 ignores the first 5 mm of key travel. But it still suggests that ES100 may be slower in terms of responding to the touch. In this connection, Roberto actually felt that the earlier part of key press seems to have more impact on GS-30 than on ES100. If so, the use of ES100 to practice soft playing may not directly translate to GS-30.

The next experiment was to check the end point of direct key engagement associated with the escapement mechanism. Roberto measures the lowest initial key position from where the sound can be made. It was about 5 mm on both GS-30 and ES100. He figured this may not be of much importance.

Anyway, on GS-30, the sound is produced based on the key press during the escapement mechanism, which is almost immediately after the start of the key press up to the let off point. On ES100, this seems to be determined by the speed when the key passes about the 5 mm point of the key press.

Now, Roberto was curious about how other digital pianos fare in this respect. Unfortunately, he has not found any relevant information online. So, he thought this "test" can be used to measure the **timing of direct action engagement**, which seems to be an important aspect of escapement mechanism. He went on to define the test as follows.

Key Travel Limiting Test (Limiting Test): To estimate how much the early part of key press would affect sound production. First, limit the maximum amount of key travel (e.g., by stacking coins in front of the key, if not "waterfall" style, or place a finger tip, e.g., in a store) and identify whether any key press within this limit can produce a sound. If there is no sound, increase the limit and retry. Then, the minimal amount of the (early) key travel to produce sound is the result of this test, measured in mm. Or, it can be casually noted as "small" (or "fast" in terms of timing) vs. "large" (or "slow"). Note that this test can be used for both acoustic and digital pianos.

Roberto actually tried this test in a few piano stores, using just his fingers to limit the key travel. The result was fairly clear. All grand pianos he tested acted like GS-30. The minimal key travel to produce sound is very small. On the other hand, digital pianos varied. The minimal key travel on many of the digital pianos he tested seemed to be even larger than ES100. There were a few models that seemed to be better than ES100. Although Roberto thought that ES100 lacks in this respect, not many digital pianos clearly outperformed it.

There is one more relevant point. More and more digital pianos are said to simulate the behavior of the repetition lever in grand pianos. That is, on grand pianos, it is possible to repeatedly strike the same note very fast while a key is half-depressed. This feature is not available in vertical pianos. It is not available in ES100 either, not having triple sensors.

Some digital pianos (usually more expensive ones) have this feature. However, when Roberto used the Limiting Test on those pianos, some of them have larger values than ES100. He thought that on some models, the ability to simulate the repetition lever might be associated with the fact that direct action engagement is slower on them.

One possibility is that a larger key travel value of the Limiting Test makes repetition lever simulation possible or easy while the *main* escapement simulation suffers. In this respect, even without the repetition lever simulation, ES100 seems to perform decently with respect to the *main* escapement simulation.

Now, this new understanding lead Roberto to pay special attention to the beginning of each key press, when the hammer starts to move, especially when playing soft. This way, he thought he was able to transfer the skills learned on ES100 to GS-30. Again, more than static touchweight (on front), understanding of the escapement mechanism may be important. Still, there is more to the differences between the key touch of ES100 and GS-30. So, he moved on.

Key Touch: Inertia

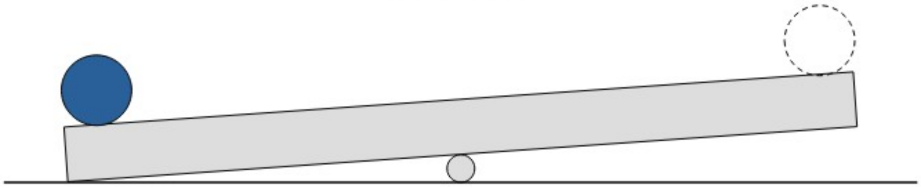
Roberto's next experiment began when he started to tap keys lightly (before making sound) and see how fast they rebound to the original position. He noticed that bass keys on GS-30 are noticeably slower to rebound than treble keys. At the same time, *all* the keys on ES100 are much faster. Still, the difference is just a fraction of a second. So, he did not initially think that it was easily measurable. However, this difference seems to be critical. And the difference in rebound speed must be associated with some dynamic aspect of key touch. So, Roberto started to pay attention to the dynamic aspect of key touch, i.e., *inertia*.

Roberto turned to the section on dynamic touchweight and inertia in Igrec (2013, pp. 298). Technically speaking, inertia is the resistance of mass to accelerate or decelerate. That is, a heavier object resists to the change in speed more than a lighter one. So, it is natural that the heavier key/action of a lower note is slower.

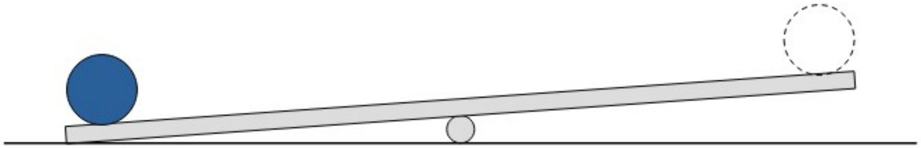
Like other parameters, inertia too affects acoustic pianos in many ways: the loudness, dynamic range, level of control in soft playing, among others. It seems to be a very complex matter. Even Igrec (2013) does not say much about quantifying inertia. Now, our focus here is between acoustic and digital piano. So, Roberto focused on how inertia might make the behavior of digital piano keys different from acoustic pianos'.

Roberto's hunch about the difference between GS-30 and ES100 was as follows. Even though their static touch weights are about the same (except for the black keys on ES100), the actual weight involved in the key movement of GS-30 is heavier than that of ES100. For example, the weight of a wooden key of GS-30 does not really affect the static weight because it is supported at the center pin and balanced. But it can affect the inertia of the key. This is just like a playground seesaw as shown in the following diagram.

Seesaw A



Seesaw B



For both Seesaws A and B, an object of the same weight can balance the seesaws.. This is static weight. However, due to the greater weight of Seesaw A itself, Seesaw A would move more slowly but once in motion, more difficult to stop. In addition, when moving up and down, Seesaw A can exert more force to the people on it.

Seesaw A and Seesaw B may correspond to a bass and treble keys of GS-30, respectively. At the same time, Seesaw A and Seesaw B may correspond to GS-30 and ES100 keys (of the same note), respectively. And regardless of the weight of the seesaw, it is always possible to determine the necessary weight to balance. So, ES100 must be designed to have about the same static touchweight as acoustic pianos without additional weight for inertia.

Eventually, Roberto came up with an idea to characterize inertia. First, he lightly tapped a bass key of GS-30 so that the key moves only a few millimeters *without making any sound*. For a small amount of key travel like this, the damper may start to rise but should not rise substantially. So, the use of the damper pedal should not be relevant. After the tap, the key will bounce back to the original position.

Next, he tapped the same key repeatedly but slowly, say, at the speed of 240 BPM (or four taps per second). To measure the speed, it would be most practical to use a metronome but a loudly ticking clock can be used as well. Since the key rebounds fairly fast, the key touch for every tap should be the same.

Then, Roberto increased the tapping speed to 300 BPM (five taps per second). As the interval of tapping becomes shorter, the next tap will happen before the key fully returns to the original position. Then, this tap will be met with the key's upward moving force. Thus, that tap will feel heavier. Actually, at this speed, every tap felt this resistance. So, the key touch was met with continuous resistance.

Then, as Roberto moves his tapping to higher notes, he noticed that the key response was different. Higher note keys moved faster and returned to the original position faster. So, he increased the speed to 360 BPM (six taps per second). Then, even higher note keys could not return to the original position in time and the finger met continuous resistance.

Note that the relatively high inertia on bass keys of GS-30 must be to compensate the heavier weight of the action. This is normally done by placing additional weights inside the front part of a key so that the static touchweight is not too heavy in comparison to higher notes.

Then, Roberto did the same on ES100. Even at 480 BPM (8 taps per second) on the lowest notes, he did not feel the same kind of heaviness as on GS-30. He could not tap any faster than that. Just to compare, he tried to do the same on his Yamaha PSR270E (electronic keyboard). No matter how fast he hits a key, it was virtually impossible to feel the rebounding force. Like most other electronic keyboards, the keys are just too springy and plasticky.

Now, here is a summary of the test results.

- GS-30: 300 ~ 360 BPM (5 to 6 taps per second)
- ES100: 480+ BPM (8+ taps per second)
- PSR270E: N/A (or ∞)

So, this can be considered a very rough way of quantifying inertia. However, even without a number, the test can be used, e.g., in a store, to quickly check inertia. As Roberto tries this many times, he can sense the level of inertia by just tapping a few keys. And this can be done on acoustic or digital pianos without anything special. Roberto's guess was that most digital pianos would be like ES100. If there are models that are even slightly closer to GS-30, the action must feel more realistic.

So, Roberto defined this test as follows:

Tapping Key Inertia Test (Tapping Test): To estimate piano key inertia by repeatedly tapping a key lightly without making sound (with only a few millimeters of key travel). The inertia must be related to the rate of tapping when the finger feels the increased force of the rebounding key *every time* the key is tapped. The result can be measured in terms of BPM (probably 240 or higher, but will be difficult beyond 480) or taps per second. Or, it can be casually noted as “slow” or “fast.” Naturally, a key with greater inertia must have a slower rate of repetition. This should be done on bass and treble.

Roberto used this test in a few piano stores. All the grand pianos behaves more or less like GS-30. Digital pianos behaved differently. In general, the more expensive models with more realistic action had higher inertia and lower Tapping Test rates.

According to Igrec (2013), static weight is important for soft playing and dynamic weight or inertia, for loud playing. However, Roberto thinks that inertia is important for both loud and soft playing. First, static touchweight is relevant only when keys are stationary. It is a sort of weight to keep or break the balance. In order to move a stationary object, inertia is involved. Then, when in use, the piano action is constantly on the move. So, it must be inertia that is more relevant all the time, especially at the beginning of key press, even for soft playing. If one depresses a key so slowly so that only static touchweight is relevant, there will be no sound.

In addition, as the Tapping Test suggests, it may have direct relevance to fast playing. Suppose that the tempo of a song is 120 BPM. A triplet of a quarter note will beat at 360 BPM. Then, playing the same note at this speed may be met with the same kind of increased resistance as explored in the Tapping Test. Thus, in such a context, the response from GS-30 and ES100 must be markedly different. Note that this is just a hypothetical scenario because keys should be fully depressed unlike the Tapping Test.

Then, Roberto wondered if the higher inertia of GS-30 might be a problem for fast playing. However, he came to think that this was not the case. When a sufficient force is applied, Roberto can repeat hitting a key fast. Of course, this requires more force. But this force and inertia may actually be helpful for fast playing. With more force, keys may rebound faster and this may help fast playing. He has felt as if the key came back fast for the next touch. This is not the case with ES100.

At this point, Roberto came to a certain realization about ES100 keys. He learned that black keys on ES100 are lighter than white ones. It has fairly low (good) touchpoint difference. And it has very low (not so good) inertia. Since all of these three factors would make the back of a black key feel light. The cumulative effect must be significance. And this actually matches Roberto’s feeling about ES100.

Any way, the main reason digital pianos tend to feel “plasticky” may be the lack of inertia involved in the key mechanism. However, inside a digital piano, it is possible to electronically adjust the parameter so that the key behavior simulates an acoustic piano fairly well. How the consequence of this arrangement affect the player must be a complex matter. It is not at all clear. Nevertheless, there may not be a good electronic adjustment to compensate for difference in inertia. In this respect, more than graded static touchweight, digital pianos may need "graded inertia" and this must have been done in some advanced models.

When Roberto practices on ES100, that should not be "damaging" the skills learned on GS-30. In this respect, ES100 is both good and bad. ES100 simulates acoustic piano actions reasonably well. Much more so than electronic keyboards (often having fewer than 88 keys), whose keys are springy and not at all responsive. However, ES100 is slightly lacking in terms of modeling escapement mechanism (indirectness, not the notch) and significantly so in terms of inertia. At the same time, he started to think that many of even more expensive digital pianos are not any better than ES100 on various fronts.

So, between his two pianos, Roberto is still working on how to calibrate his touch, especially immediately after switching instruments. But making such a transition for so many times, he thinks he can improve his ability to do this. In a sense, he started to internalize the sense of both of his instruments as well as their differences. So, in the end, the two pianos are becoming a sort of hybrid piano in his mind.

The Next Digital Piano

As mentioned earlier, Roberto is in search of a digital piano that will replace ES100. In addition, the new digital piano will become the only piano after downsizing. So, he wants its action to be as close to that of a grand piano as possible. He started with reviews and comparison articles online. But he was not very satisfied. There is little about the three Diagnostic Properties, maybe except for touchpoint difference in some cases. Some are completely subjective. He felt that he needs to do this on his own.

Roberto's ideal solution might be an acoustic piano which *can* silence the strings and produce sounds digitally. Then, its action always stays as that of an acoustic piano. Surely, there are pianos like that: e.g., Kawai's AnyTime Hybrid Grand Piano and Yamaha's Silent Piano (upright). If Roberto is to assign his own **Action Realism Index** to these, that would be 5 out of 5 (5/5). Note that this index is *not* about the quality. That is, having a real action does not guarantee that. Any way, these types of pianos are well beyond Roberto's budget and not at all easy to move around either.

The next level would be hybrid pianos which involves no strings. Probably the most attractive one would be Kawai's NV-10. It actually contains a replicated grand piano action. As such, the key touch is very close to a real grand piano. NV-10 also simulates the effect of the damper pedal on key touchweight. That is, when the damper is pressed, keys become lighter. Probably still missing is the actual movement of the keyboard when the soft (una corda) pedal is depressed. Roberto's action realism index for this class would be 4/5, losing one point for the action being non-functional. Note that certain models in this category may still have their own issues (more later). But again, this is still beyond his budget and still too bulky.

Considering the price and portability, the next group of candidates are high-end portable digital pianos. Roberto limited his search to the three leading digital piano manufacturers, i.e., Yamaha, Roland, and Kawai. Although he also considers stage pianos, Yamaha and Roland stage pianos are excluded because their actions do not seem to be substantially better. Some of Kawai's stage pianos have fairly long "seesaw" keys made of *solid* wood (e.g., MP11SE). Then, high-end portable models include advanced "folded" key mechanisms (e.g., Yamaha P-515, Roland FP-90X, Kawai ES920). P-515 and FP-90X have partially wooden white keys. Although Roberto wanted to try all these, most of them were not available in local stores. So, he also tried console digital pianos with the same (or related) actions as the above-mentioned portables (e.g., Yamaha CLP series, Roland LX/HP series, Kawai CA/CN series).

Here is a list of digital pianos involved in this process.

Mfr.	**Portable Models**	**Action**	Console Models
Yamaha	P-45/125	GHS	
	P-515	NWX	
		GT-S	CLP-725/745
		GT	CLP-775
Roland	FP-30/60X	PHA-4	HP-702
	FP-90X	PHA-50	HP-704, LX-705
		Hybrid Grand	LX-706
Kawai	(ES100)	(AHA IV-F)	
	ES110/520	RHC	
	ES920, MP7SE	RH III	CN29/39
	(MP10)	(RM3 G)	
	MP11SE, (MP11)	GF	
		GF III	CA79/99

Large font: Roberto's primary candidates
Grayed: Not available in local stores for testing
( ): No longer in production

Naturally, the reference point for this search is ES100. The new piano must be significantly better. So, Roberto pay close attention to his Diagnostic Properties: touchpoint difference, direct action engagement timing, and key inertia. He did not think that sound would be an issue.

Touchpoint difference: Roberto was quickly able to identify actions that are not as good as AHA IV-F (ES100) in this respect. These include GHS, GT-S, PHA-4, and RHC. According to online information, the pivot lengths of these actions are 19.5 cm or less. The force ratio is 2.9 or more. Surprisingly, one of Yamaha's hybrid models, NU1X, had very poor touchpoint difference. Again, online information backed this up; its pivot length seems to be only 18 cm.

The actions clearly better than AHA IV-F were PHA-50, and GF. Their pivot length are 22 cm or longer. When fully depressed, the back of a black key is also very low and the slope is almost flat. In fact, their touchpoint difference is comparable to grand pianos (i.e., force ratio of around 2).

Between the above two groups are RH III and RM3 G. Manual test seems all right. However, according to online information, their pivot lengths are shorter than ES100.

Direct action engagement timing: For this Property, Roberto used the **Key Travel Limiting Test**. First, he did this on grand pianos. He was able to confirm that Steinway Model O, Yamaha C2X, and Kawai GX-3 all behaved like GS-30. They all have very small minimal key travel during the Limiting Test. It was possible to produce sound with a very shallow key press. That is, these actions respond to the initial part of key press immediately.

On the other hands, digital piano models behaved differently. Note that Roberto used just fingers to limit the key travel; so the assessment here remains subjective and tentative. Other people should be able to quantify, though.

He felt that the following actions have larger (i.e., worse than AHA IV-F) minimal key travel during the Limiting Test: GHS, GT-S, GT, and PHA-4. These include virtually all of Yamaha models he tested. This suggests that the technique required to play soft on these models be different from that on acoustic pianos. This can be a major issue. Although Roberto did not have a chance to test P-515, he extrapolated the outcome and guessed that the NWX action in P-515 behave similarly. So, at this point, he became reluctant to pursue Yamaha models any more.

Next, PHA-50, RH III, RM3 G, and GF all seemed better than AHA IV-F. Since Roberto did not do the actual measurement, it is hard to tell by how much. But he had a sense that PHA-50 might be the best in this regard.

Key inertia: For this Property, Roberto used the **Tapping Test**. Again, the grand pianos he tested behaved like GS-30. However, Steinway Model O and Yamaha C2X might have been slightly lighter (dynamically) than GS-30. For this property too, Roberto did not quantify; so his assessment remains subjective and tentative.

Next, this is the property AHA IV-F lacks most. But GHS, GT-S, and RHC are just like AHA IV-F. There is not much inertia and the keys are light (dynamically).

Then, GT, PHA-4, PHA-50, RH III, RM3 G, and GF are all clearly better than AHA IV-F. It is possible to feel the tapping resistance much clearly at slower tapping rates. The clear difference between RHC and RH III must be due to the inclusion of counterweight beneath each key. In addition, RH III seems to be different in the following way. According to an online image, RH III keys have a slight protrusion behind the pivot point. So, this might be considered a quasi-seesaw. In addition, there seems to be a weight below the protruded section. These weights may be used to increase inertia. At the same time, using the space behind the pivot might have costed the pivot length. Between PHA-4 and PHA-50, the latter seems much better. But regarding GT, the greater inertia may also be perceived as heaviness or sluggishness.

After these tests, Roberto's final pick actions (in portables) were: PHA-50, RH III, RM3 G, and GF. These outperform others. However, there were a few additional considerations.

Although RM3 G shares a lot of features with GF, there are a few differences. First, its pivot length is much shorter. So, its touchpoint difference is worse. According to the image on a web site, it is about the same as RHC, even worse than AHA IV-F. Roberto did not feel that the touchpoint difference of RM3 G was that bad. The actual feeling might have been saved by the seesaw action and other factors. However, this can be a problem. Second, the top side edges of black keys are not as smooth as most other models. This makes it somewhat difficult to access a white key in between. So, Roberto clearly prefers GF to RM3 G.

On a related note, there is another Kawai product, VPC1, which is a MIDI controller with the RM3 G-II action (supposedly a newer version of RM3-G). He was interested in it because it has an action with wooden keys and is less expensive than MP11SE. He dropped this product much earlier because he was not sufficiently confident to handle possible USB-MIDI latency when connected to a computer. However, he now has another reason to avoid this product, which is its short pivot length.

Next, RH III too has a relatively short pivot length. According to some online image, it is about 20.5 cm, again, shorter than AHA IV-F. Although he did not feel much of difficulty using the back of keys, he wondered if this could become a sticking point.

This leaves PHA-50 and GF. As far as action is concerned, Roberto did not find any obvious shortcomings with respect to his Diagnostic Properties. Thus, his Action Realism Index for these two would be 3/5, one full point for each of the Properties. Beside those with a real or replicated action, this is the best possible. In comparison, the Index for RM3 G and RH III would be 2.5/5 and 2.75/5, respectively, losing points for shorter pivot length. Yamaha GT would be indexed 2/5, losing one point for its poor Limiting Test result. His reference action, AHA IV-F, would have 1.5/5, the sum of one point for decent touchpoint difference and 0.5 for the so-so the Limiting Test result. Other tested models would be indexed lower than that. So, Roberto came to a realization that AHA IV-F in his ES100 is not so bad after all.

Now, the digital piano Roberto used to test the PHA-50 action was HP-702. Although he thought that the action itself is excellent, he did not at all like the sound of HP-702 (SuperNATURAL) through headphones. Note that it is important to use headphones to eliminate the impact of room acoustics. His reaction may be because he is used to Kawai sounds. Or, it may be due to Roland's approach to heavily "model" sound. In contrast, he did not have any sound issues with Yamaha models. Just in case, he also tested LX-705, which has the "improved" PureAcoustic sound engine. He tried all four concert grand sounds but was still not very comfortable. So, despite the excellence of PHA-50, Roland models are out. Prior to this, he thought that the sound of all recent digital pianos is good. But he had to change his mind.

In contrast, Roberto has no problem with the Kawai sound, being used to the "EX Concert" of ES100. Newer Kawai models also include "SK Concert," which is the current top of the line. Roberto thought that the SK sound is certainly different from EX sound, especially in the bass. SK's bass sounds may be "purer" in the sense that it has less harmonics. Some might say SK is more "European" than "American." But he does not really need the SK sound. If he had a choice, he might well choose the EX sound, because GS-30 is much more like EX than SK.

In the end, Roberto's finalist was the GF action, which is in MP11SE (with the SK sound) and MP11 (without SK). Actually, it was not a surprise. A lot of online reviews pick this action is the best for portables. Now, he wonders how the two distinctive features of this action would compare with other actions. First, as for solid wood keys, he certainly *felt* the difference compared with RH III. However, this is not something Roberto was able to quantify or characterize clearly.

On a related note, Roberto did not much think of the difference between all plastic and partially wooden (white) keys. The use of wood in this case seems like more of a "show." Note that his reaction is based on comparing CLP 725 (all plastic) and 745 (white keys partially wooden), both of which has the GT-S action. Next, PHA-4 and PHA-50 have all plastic and partially wooden white keys, respectively. However, these two actions are very different in construction. As a result, they perform quite differently in all three Diagnostic Properties. So, the clear superiority of PHA-50 seems to come from factors other than partial use of wood.

Second, as for the seesaw action, Roberto thought about a few potential benefits. Due to the existence of the rear part behind the pivot, it must be more straightforward to balance the key itself and simulate a realistic level of inertia. Next, since the front half of keys are almost the same as the acoustic piano action, the feeling and the sound of hitting the key bed is very realistic. However, even with a folded action, PHA-50 works great. So, the question of seesaw vs. folded may not be a decisive one.

Toward the end of this process, Roberto was still comparing GS-30 and ES100. There still are subtle differences not discussed so far. For example, there is more to the "notch" felt at the let off point. The sensation is actually due to the complex interaction between the jack and the hammer shank around a part called "knuckle." Note that this interaction occurs on both ways of key travel, i.e., down and up. As a result. And Roberto feels that there is a sort of bump even while the key returns to the original position. Since only the downward movement of a key is relevant to sound production, the digital piano manufacturers try to simulate the let off point only for the downward travel. But would some of them include "notch" on both ways in the future? Roberto is not sure but also feels that manufacturers like (not necessarily functional) "show." Any way, he continues to think about the difference between his two pianos.

At this point, Roberto had to face one more factor: price tag. His finalist MP11SE (or even discontinued MP11) is the most expensive model(s) among his candidates. Yet, it is still *not* a real action, not even a "realistic" one (as in NV-10). If he compares MP11SE with the runner up, which is ES-920, the price difference is substantial. Would it worth? It will be a matter of compromise in either way. Also during this process, Roberto happened to compare a variety of console-type digital pianos as well. If he was searching for a console model, his pick would be Kawai CA79 with the GF III action (successor of GF). But again, price is another issue.

Conclusion

In this document, we follow Roberto's path to explore the difference between acoustic and digital pianos, repeatedly referring to his two pianos, Kawai GS-30 and ES100. This effort is mainly to improve his ability to transfer skills between his pianos. But he is also interested in replacing his ES100. Thus the information should be useful in that respect too.

The main area discussed here are sound and key touch, including some details on static touchweight, escapement, and inertia. During the process, Roberto identifies three Diagnostic Properties: touchpoint difference, direct action engagement timing, and key inertia. We also discuss several test methods: pivot length/force ratio calculation, Key Slope Test, Key Travel Limiting Test, and Tapping Key Inertia Test.

Surely, there are online reviews and comparison articles. However, many of them are very limited in scope, e.g., only dealing with front static touchweight, or entirely subjective. Roberto tries to be more comprehensive and more systematic. For example, his test methods can be used to quantify the Diagnostic Properties to some extent, so that the results can be shared and compared openly with other people. And of course, the relevance and usefulness of these Properties can also be discussed, especially in comparison to people's actual perception about them.

During the exploration, Roberto also realizes certain aspects that are *not* so critical. These include: static touchweight only at the front of a key (in comparison to touchpoint difference), static touchweight grading (in comparison to key inertia grading), damper influence on touchweight (available only in NV-10), escapement notch (in comparison to direct action engagement), and partial use of wood.

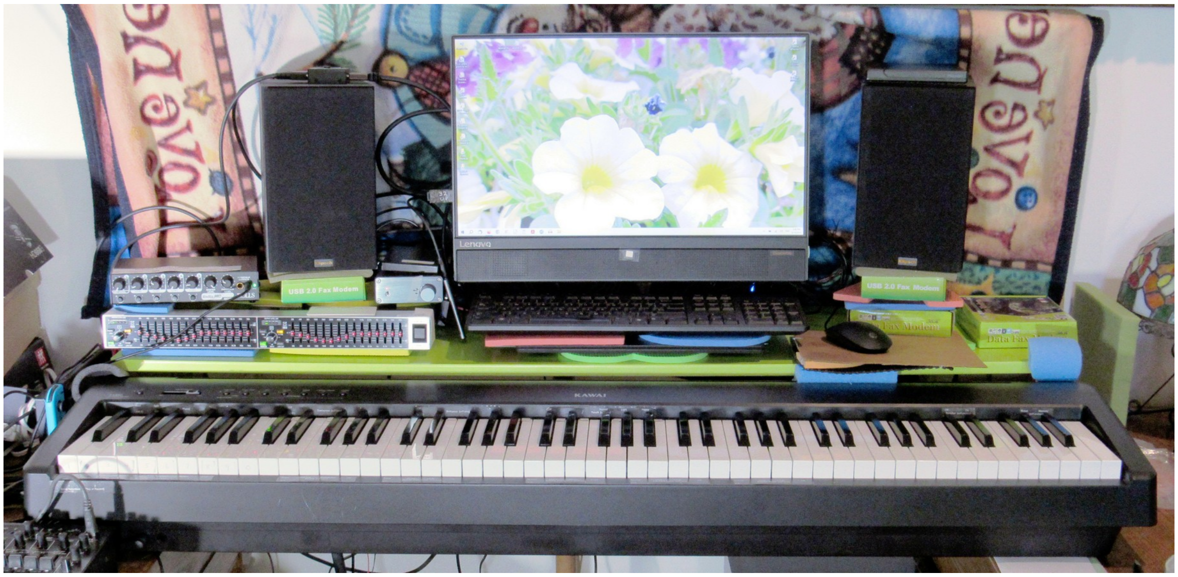
Through this exploration, Roberto has learned a great deal and can now articulate the difference between his two pianos in more concrete terms. In particular, knowing where his ES100 lacks made him more confident with respect to transferring skills between his pianos. And when the time comes, he should be in a better position to choose the next digital piano.

Update (September 14, 2023)

- Rolls mixer (Minimix 2, MX51S) was replaced with MiniMix PRO MX122. This added one more input channel and separate control for the main and headphone outputs. MX122 is substantially more expensive but the additional functions are very useful.

- Behringer graphic equalizer (FBQ800) failed and was replaced with FBQ1502HD. FBQ1502HD is more expensive but the product seems more well-built.

- Sound level setting: Especially with the MX122, Roberto now has more points to set sound levels. His general approach was to do this in the order following the path from a sound source to the speakers. In general, he raised the sound level as much as he could before the max level exhibits distortion. This way, the noise level would be minimized.



Update (March 5, 2024)

Roberto finally had a chance to try Yamaha P-515 in a store. Here are a few points from his experience.

- First, Roberto casually tried the three tests discussed in this document (i.e., no objective measurements). The Slope Test result seemed to be good. The Tapping Test result too seemed decent. However, like other Yamaha models, the result of the Limiting Test was not so good. To him, the sound can be produced only during the later part of key press. So, even if he tries to visualize that a hammer hitting a string during the earlier part of key press, he couldn’t do it well. His impression was that the sound was being produced when the key hit the key bed, which is not actually happening in a grand piano action.

- Another impression of P-515 was that it felt somewhat “tiring” to play it. This seems to align with some other people’s comments that the action of P-515 (or Yamaha digital pianos in general) are relatively “heavy.” While the static weight of Yamaha digital pianos in general may be slightly higher than others, it is not significantly so. Note that one may not even notice the 25% change in the static weight while using the damper pedal of a grand piano. At this point, Roberto came up with one property that might be relevant. That was friction. So, he devised a new test. Since working on a single key may not be sufficient to exhibit noticeable outcome, he tried to deal with multiple keys at the same time to amplify the effect. First, place a ball-point pen (or something analogous) on seven (or more) of white keys (say, from the middle C). Very slowly press the entire pen down to the key bed without producing sound. Then, move the pen up and down very slowly so that there still is no sound (if there is escapement simulation, avoid the involved area). The force of the rebounding keys should corresponding to upweight; the force to press the keys down should corresponding to downweight. Both of these are *static*. Since the movement is very slow, inertia must be irrelevant. Then, the sensation associated with slowly moving the keys up/down might be associated with the friction of the key movement. Let’s preliminary call this **Friction Test**. Roberto tried this on P-515, Yamaha YDP-184 (GH3), Roland RD-107 (PHA4), and Kawai KDP-120 (RHC-II). There were noticeable differences. Moving keys up/down on P-515 was substantially more “effortful” than doing so no KDP-120. His estimate on the order of “effortfulness” was as follows: P-515 > YDP-184 > RD-107 > KDP-120. Roberto’s speculation is that Yamaha digital pianos tend to have higher friction and this is reflected in his and other people’s impressions. Although he did this casually in a store, he thinks that this test too can be formalized, just like other tests in this document. Oh, if we do the Friction Test on an actual grand piano, it is not that “heavy.”

Appendix: Digital Piano Action Check List

By using the following check list including Roberto's three Diagnostic Properties, we can quickly estimate how well the action of the digital piano in question simulates those in acoustic pianos.

1. Touchpoint Difference

- If the pivot length is known: Calculate the force ratio (p. 9)
- Using a side-way key image: Calculate the pivot length and force ratio (p. 9)
- Key Slope Test: Check if the slope is steep, i.e., worse (p. 10)
- Compare the front/back touchweight manually

2. Direct Action Engagement Timing ~ Key Travel Limiting Test (p. 14)

Limit the key travel using a stack of coin or a finger. Measure the minimal key travel that produce sound. Do this on a few different keys. Acoustic pianos have a very small key travel. The larger the key travel, the action may feel slower in timing to produce (soft) sound.

3. Key Inertia ~ Tapping Test (p. 17)

Tap a key repeatedly without making sound. Identify the rate (BPM or taps per second) when the finger feels the resistance of the rebounding key *every time*. Do this for both bass and treble sections. The smaller the rate, the larger the inertia. A typical grand piano may have the rate of 300 ~ 360 BPM, slower on bass keys.

Then, of course, we need to play actual music, using both the front and back of keys, very softly, loudly, and fast. Also, we should use headphones (preferably our own) to check the sound quality, to eliminate the effect of room acoustics.

Update (November 19, 2021): There is a related document, *Digital Piano Key Action Diagnostic Properties*, focusing on practical aspects of analyzing digital piano key touch (https://archive.org/download/ogm21-piano2/ogm21-piano2.pdf).

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